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LOCAL DETECTION OF CHEMICAL AGENTS. EFFECTIVENESS OF DETECTORS FOR "OFF-TARGET" CHEMICAL ATTACKS WITH NON-PERSISTENT AGENTS (U)

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by

P.B. Neale and T.F.S. Tees

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Technical Paper No. 18

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March 1971

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C.D.E. TECHNICAL PAPER NO. 18.
DATE: MARCH 1971

AD-595647

LOCAL DETECTION OF CHEMICAL AGENTS. EFFECTIVENESS OF DETECTORS FOR "OFF-TARGET" CHEMICAL ATTACKS WITH NON-PERSISTENT AGENTS

by

P.B. Neale and T.F.S. Tees.

ABSTRACT

The use of a local detector/alarm system of defined characteristics, in the context of an "off-target" chemical attack, by a chemical agent cloud originating from an instantaneous point source, is considered. A simple cloud diffusion model is used to calculate the dosages accumulated by personnel. The significance of these doses with respect to casualty production is considered for a typical nerve agent.

The characteristics required by an automatic local detector are specified, and it is recommended that assessments should be made of probable casualty levels to troops relying on such detectors, who are subjected to off-target attacks with nerve agents, paying particular attention to certain means of agent delivery.

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Definitions

Alarm	A device which provides a visual or audible signal as warning of the presence or the approach of a chemical agent.
Chemical Detection.	The use of instruments or the senses, to establish the presence of a chemical agent.
Chemical Monitoring.	The act of detecting and/or measuring the hazard at a specified point.
Chemical Survey.	Directed efforts made to determine, and to mark, the extent of chemical contamination in an area and to measure the degree of hazard.
Chemical Surveillance.	The systematic observations of areas, or the air above them, by visual, electronic, photographic or other means for chemical intelligence purposes.
Confirmation Monitor.	A device which confirms the absence of harmful concentration of chemical agent vapours or aerosols and indicates when the respirator can be removed with safety.
Contamination Monitor.	A device which detects the presence of significant amounts of chemical agents (on the ground or on men, vehicles, equipment or stores) before or after decontamination.
Detoxification level.	That concentration of chemical agent which can be tolerated indefinitely by unprotected personnel.
Early Warning.	This is the provision of warning in time for suitable evasive action, or protective measures, to be taken.
Early Warning Detector.	A device which detects chemical agents at an appreciable distance from personnel and enables them to receive early warning.
Local Detector.	A device which determines the presence of significant amounts of chemical agents in its immediate vicinity.

Source.

A munition or system for the dissemination of a chemical agent, e.g. bomb, shell, spray, or a site or area of chemical contamination giving rise to chemical agent vapour or aerosol.

Symbols

C^{o}	The peak concentration in an agent cloud (puff) existing at its centroid.
C_{xyt}	The agent concentration in an agent cloud at position (x,y) at time (t).
C^{*}	The minimum concentration of a chemical agent to which a detector responds. Detector sensitivity.
$D^{T}\ x,y$	The total dosage of chemical agent at point (x,y).
$D^{P}\ x,y,t$	The partial dosage of chemical agent at point (x,y) and for time zero to time t.
D^{*}	The critical casualty dosage (Assumed = 5 $mg.min/m^{3}$).
ICt_{5}, LCt_{50}, ECT_{90}	The incapacitating, lethal, and effective dosages for a chemical agent resulting in 5%, 50%, and 90% casualty levels respectively. Note that these values refer to a definite breathing rate.
h	The effective height of an agent cloud. If a normal Gaussian distribution of concentration is assumed then the concentration of agent at height h from the centroid is $C^{o}/10$.
I,N,P	Meteorological categories corresponding to states of Lapse, Neutral and Inversion respectively.
Q	The effective strength of an agent source, i.e. the mass of agent.
t	Time.
T_{e}	Time of exposure of personnel to agent ($T_{e} = t_{c} + t_{r} + t_{m}$).
t_{c}	Trigger time. Time interval from source burst to establishment of C^{*} at the detector.
t_{m}	Masking time. Time interval from t_{r} until completion of masking.
t_{r}	Response time. Time interval from t_{c} until the sounding of the alarm.
v	Wind speed.

w	The width of an agent cloud. If a normal Gaussian distribution of concentration is assumed then the concentration of agent at distance w/2 from the centroid is $C^o/10$.
x,y	Downwind and crosswind co-ordinates from the source.

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by

P.B. Neale and T.F.S. Tees.

SUMMARY

AIM The aim is to investigate the use of a local detector and alarm in the context of 'off target' chemical attacks. This preliminary study is limited to consideration of the use of a single detector positioned in a vehicle, or at a defended position, or at some operationally realistic distance from a defended position, to provide personnel with warning to mask.

METHOD OF STUDY An operational model is assumed in which personnel using a detector/alarm system of defined characteristics are subjected to an 'off target' attack by a chemical agent originating from an instantaneous point source e.g. an aircraft bomb. A simple cloud diffusion model is used to calculate the dosages accumulated by personnel. The significance of these dosages with respect to casualty production is considered for a typical nerve agent.

CONDITIONS USED IN STUDY

Detector Characteristics

C^*, Critical response concentration, $mg.m^{-3}$	0.01, 0.1, 0.5, 1.0
t_r, Alarm response time, s.	0.
t_m, Masking time, s.	10, 30, 60, 90.

Meteorological Conditions

Lapse, category I; 5 knot wind.

Neutral, category N; 5, 10 and 15 knot winds.

Inversion, category P; 5 knot wind.
(5 knots $\sim$ 2.6 m. s^{-1})

Instantaneous Point Sources

Q, Source strength, Kg. 100, 250, 500, 1000.

Detector and Troop Positions

Within the boundaries of the agent cloud out to a range of 4 Km from the source.

CONCLUSIONS

(i) The characteristics required by an automatic local detector (assuming masking time, t_m, is zero) for use in 'off target' attacks to detect chemical agent vapour and aerosols from munitions bursting upwind are:-

Response time $t_r \leqslant 10$ s.
Critical Detector Sensitivity 0.01 to 1.0 $mg.m^{-3}$.

(ii) If the detector device is also required to fulfil the roles of chemical monitoring then the required characteristics become:-

Alarm Response time $\leqslant$ 10 s.
Critical Detector Sensitivity $\leqslant$ 0.01 $mg.m^{-3}$.

(iii) The nerve agent detector, M8, will not give sufficient warning to eliminate entirely the hazards from nerve agents in the field. However a significant reduction in hazard may be achieved if it is used intelligently.

(iv) Without further detailed analysis it is not possible to recommend an optimum detector emplacement. Present information indicates an upwind emplacement of 100 to 200 metres, and, if more than one detector is available, a crosswind detector spacing of approximately 200 metres.

(v) The most hazardous meteorological conditions occur when there is a zero or positive temperature gradient and high wind speed, the latter may be 15 knots under Neutral conditions.

(vi) In order to minimise the hazard from 'off target' attacks it is essential to minimise the masking time.

RECOMMENDATIONS. Assessments should be made of probable casualty levels to troops relying on automatic local detectors who are subjected to 'off target' attacks with nerve agents; particular attention should be paid to the following means of agent delivery, (a) single large source e.g. an aircraft bomb, (b) multiple small sources e.g. multi-barrelled rocket launcher, (c) area contamination by coarse spray.

PBN/TFST/HC

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LOCAL DETECTION OF CHEMICAL AGENTS. EFFECTIVENESS OF DETECTORS FOR "OFF-TARGET" CHEMICAL ATTACKS WITH NON-PERSISTENT AGENTS.

INTRODUCTION

1. The wearing of the present NBC ensemble imposes an additional work load on the individual soldier and may reduce his combat efficiency; for this reason it is not considered practicable for him to adopt a fully protected posture continuously. (1) Current doctrine teaches that the NBC suit, gloves, and overboots will be worn continuously and that the respirator will be donned as required (2). Thus the respiratory work load imposed by the respirator is minimised while retaining the ability to attain full protection rapidly. Troops are taught to mask immediately in the case of 'on' target attacks when the arrival of munitions provides warning; however, no such warning may be received in 'off' target attacks. In the latter case, devices are required which detect the presence of chemical agents and give visual and/or auditory warning of their arrival.

2. Three chemical detector devices are in service or under development:-

(a) Detector Papers (GSR 3101/3102). Such papers are at present in service and give warning of the arrival of liquid droplets down to 50 μ m diameter. An automatic device for detecting droplets is being developed in the U.S.A.

(b) Long Range Detector, Early Warning (GST 3032). This must give warning of an approaching chemical 'cloud'. Such equipments are at present in the research and development stage, e.g. active and passive LOPAIR and LIDAR, but none is yet in service.

(c) Local Detector and Alarm (NGASR 3100). This is required to detect the presence of chemical agents - vapours or aerosols - at the site of the instrument. Such equipments are now entering service and this study is concerned with their use.

AIM

3. The aim is to investigate the use of a local detector and alarm in the context of 'off target' chemical attacks. This preliminary study is limited to consideration of the use of a single detector positioned in a vehicle, or at a defended position, or at some operationally realistic distance from a defended position, to provide personnel with warning to mask.

METHOD

4. An operational model is assumed in which personnel using a detector/alarm system of defined characteristics are subjected to an 'off target' attack by a chemical agent cloud originating from an instantaneous point source e.g. an aircraft bomb. A simple cloud diffusion model is used to calculate the dosages accumulated by personnel. The significance of these dosages with respect to casualty production is considered for a typical nerve agent.

USE OF LOCAL DETECTORS

5. Technical Aspects. Detectors are required to possess a wide range of characteristics as follows:-

(i) Detection capability.	Will detect vapours and aerosols of all current (and forseeable) chemical agents automatically; no response to chemicals other than chemical agents.
(ii) Sensitivity. (Concentration/ Time)	Adequate to detect any chemical agent hazard, the latter being determined partly by medical aspects and partly by operational concepts (see below).
(iii) Structure.	Small size and weight, man portable yet adaptable to vehicle mounting; low power requirement, compatible with present vehicular power systems.

(iv) Reliability.	Rugged and reliable with low maintenance and no false alarms; unaffected by wide changes in environment (e.g. temperature, relative humidity, dust).
(v) Low Cost	To permit issue at 1 per vehicle or 1 per platoon.

The requirements are unlikely to be met in full since they describe an ideal instrument; the instrument developed for the Services must be selected on the basis of detector performance versus cost.

6. Medical Aspects. Ideally, detectors should detect aerosols and vapours from all agents at concentrations down to the agent detoxification levels (3). Present detectors are designed to respond primarily to nerve agents for which typical detoxification concentrations are $\sim 0.007\ mg.m^{-3}$ for GB/GD and $\sim 0.004\ mg.m^{-3}$ for VX (Ref. Table 1). Such concentration sensitivity is difficult to achieve in combination with other required characteristics, and the NATO criteria (4) set more easily attainable sensitivity targets designed to ensure that personnel are not exposed to an incapacitating dosage. These NATO criteria have not so far been met (the US/M8 system can respond to nerve agent concentrations $\geqslant 0.1\ mg.m^{-3}$ in response times $\leqslant$ 2 minutes). Thus in order to minimise the chemical agent hazard, the best possible procedures for the use of the available detectors must be devised.

7. Operational Aspects. Concepts of use for local detectors have been reviewed recently (5) and are summarised in Table 2: Fig. 1 is intended to complement this Table. Detection of both persistent and non persistent agents is required to minimise the hazard in the various possible types of attack.

8. 'On target' attacks with non-persistent agents will be mounted to produce high concentrations of aerosols or vapours quickly (seconds) i.e. attacking via the respiratory route before masking can be achieved. Casualty levels will depend on the delay in masking. 'On target' attacks with persistent agents can cause casualties by means of both respiratory and

percutaneous absorption into the body. Vapour concentrations will be lower than those with non-persistent agents and percutaneous absorption is relatively slow and may be countered by personal decontamination. Casualty levels may be high when personnel are unaware of the attack. All 'on target' attacks must be countered by observation of unusual enemy activity, observation of initial symptoms in others, warning provided by local alarms and detector papers, and by immediate action (IA) drills.

9. Both persistent and non-persistent agents will give rise to a vapour hazard downwind of the 'on target' area; however the hazard from non-persistent agents will be of short duration in comparison with that from persistent agents. As the vapour cloud drifts downwind, it will expand in size while the agent concentration decreases. Personnel in the downwind path may have received a broadcast warning from the 'on target' area, otherwise they must rely on their local detectors. The hazards resulting from this 'off target' attack will depend on various factors including:- (i) the detector characteristics, (ii) the cloud characteristics, (iii) the environmental conditions (ground and meteorology) and (iv) the positions of the detector and the personnel in the cloud path. Each of these factors will be considered separately.

MODELS ASSUMED FOR DUTY

10. Detector Model. The essential functional parameters of a local detector and alarm system are:-

(a) Detector sensitivity (C^*) i.e. the minimum agent concentration to which it responds.

(b) Detector response time (t_r) i.e. the time lapse between exposure to the threshold concentration and visual or auditory warning.

In general, for present detector/alarm systems (e.g. the US-M8), agent concentration and response time are related by some complex function, which varies from agent to agent as shown in Figure 2. In order to simplify the calculations in this study a detector model having various combinations of fixed parameters (C^* and t_r) was assumed.

11. All possible alarm situations may be considered on a go, no-go, basis once these parameters have been selected. If the cloud is assumed to have a normal distribution of concentration around its centre (Figure 1(i)), then an alarm sited on the wind line through the cloud centre will be subjected to the peak cloud concentration at that downwind distance, and for an alarm sited off the wind axis the maximum concentration will be less than the peak concentration.

If the detector sensitivity is greater than the maximum agent concentration, then the alarm will not be triggered; troops will receive no warning and will be exposed to the full agent dosage passing that point. If however, the maximum agent concentration is greater than the detector sensititivity then the alarm will be triggered. In this case the time (t_c) after source burst at which the agent concentration at the detector equals the sensitivity may be calculated. The alarm will be given to the troops at time (t_r) after this and the troops will have masked after a further time (t_m)*. Thus the troops will remain unmasked for a total time (T_e) from burst, where

$$T_e = t_c + t_r + t_m. \qquad 1.$$

If the alarm is not triggered then $T_e = \infty$ and troops will experience the maximum possible agent dosage passing their position; if the alarm is triggered then the dosage experienced by the troops will be lower than this maximum value.

*Note that the chemical defence training manual (2) recommends that troops hold their breath while masking i.e. during time t_m.

12. <u>Cloud Diffusion Model</u>. The agent is assumed to be released as an instantaneous point source which travels downwind in a constant direction as a cloud (puff) at wind speed (v); the cloud expands by diffusion during travel and the agent concentration $C_{x,y,t}$ at ground level at downwind co-ordinates (x, y) and at time (t) after release, follows a normal Gaussian distribution about its centroid as described by the

equation:-

$$C_{x,y,t} = C^{o}_{x,y,t} \exp - h^{2}\left[\frac{(x - vt)^{2} + y^{2}}{w^{2}}\right] \qquad \text{- - - - - - - - 2}$$

Graphs of cloud width (w) versus downwind distance of travel under various meteorological conditions are available (6); in these graphs cloud width is related to the limits of crosswind oscillation of the cloud during its travel downwind, and thus the agent concentration described in the above equation is a 'time-mean' concentration (7).

13. Unprotected personnel at point (x,y) would be exposed to a total agent dosage given by the equation:-

$$D^{T}_{x,y,} = \int_{o}^{\infty} C_{x,y,t}\, dt. \qquad \text{- - - - - - - - 3}$$

Personnel at point (x,y) relying on a local detector at point (x'y') would be exposed to a partial agent dosage (subject to the conditions described in paragraph 9 above) given by the equation:-

$$D^{P}_{x,y,Te} = \int_{o}^{Te} C_{x,y,t}\, dt. \qquad \text{- - - - - - - - 4}$$

The derivation of the expressions for these dosages and the computer programme for their computation are described in Appendices 1 and 2.

14. Environmental Model. The terrain is flat and open and is free from buildings, trees etc. which will affect the dispersion of the agent cloud. Thus, over the distance of cloud travel the wind vector is constant and such crosswind oscillations of cloud centroid as occur are due to minor fluctuations in wind direction. The turbulence responsible for cloud diffusion is due to frictional effects between the terrain and the wind and to thermal effects depending on the meteorological condition. The meteorological condition is characterised by the wind speed and the thermal gradient in the lower layers of the atmosphere, the latter being either lapse (temperature decreases with height, negative gradient, condition of maximum turbulence), neutral with zero temperature gradient, or inversion (positive temperature gradient, condition of minimum turbulence and maximum stability).

15. Operational Model. The possible relative positions of the agent source, the troops, and the detector, within the area swept by the agent cloud are shown in Figure 3a. In Figure 3b, the dosage distance relationships corresponding to these various positions are shown, and the extreme positional arrangements with corresponding dosages are listed in Table 3. These diagrams and the table are discussed below.

Case No.1 Region SA. The immediate target area extending a distance of 0.5 Km downwind from the point source. Attacks are considered to be 'on target' and the dosage accumulated will depend on the masking time t_m.

Case No.2 Region ABEF. The downwind area within which the local detector can be used effectively. Attacks beyond A are considered to be 'off target'. The local detector will be relied on to provide warning and its efficiency will depend on its crosswind position relative to the cloud axis. When the detector is on the wind axis (2a to d, Table 3), troops with the detector will receive a partial dosage D^p_{ABEF}, while those positioned directly crosswind will receive a lesser dosage approaching zero as they approach the cloud boundary. Troops downwind of a detector will receive a lower dosage than those with the detector; this dosage will be zero at sufficient detector-troop separation. When the detector if off the cloud axis (2e,f,g, Table 3) there will be a longer alarm delay culminating in failure to provide a warning when the peak concentration achieved at the detector fails to reach its critical sensitivity. Troops on the axis will receive increasing dosages as the crosswind distance of the alarm from them is increased. Troops off the axis with the alarm will probably receive a dosage less than the partial dosage they would experience on the axis. Note that troops directly downwind of a detector on the cloud boundary (assuming $C^o/10 < C^*$) will accumulate the total possible dosage at their position.

Case No. 3 Region FN. A region of possible hazard in which the detector will fail to operate. In this region the peak cloud concentration is below the detector sensitivity level. Personnel receive no warning and accumulate the total dosage at their position.

Thus over certain regions of downwind distance and depending on the positions of the detector relative to the cloud axis, the warning provided by the detector will reduce the hazard to personnel. The remainder of this report describes the results of calculations of this residual hazard.

CONDITIONS AND CONSTANTS USED IN CALCULATIONS

16. Detector Characteristics

C^*, Critical response concentration, $mg.m^{-3}$	0.01, 0.1, 0.5, 1.0
t_r, Alarm response time, s	0.
t_m, Masking time, s.	10, 30, 60, 90

17. Meteorological Conditions

Lapse, category I; 5 knot wind.
Neutral, category N; 5, 10 and 15 knot winds.
Inversion, category P; 5 knot wind.
(5 knots $\sim$ 2.6 $m. s^{-1}$)

18. Instantaneous Point Sources +

Q, Source strength in Kg. 100, 250, 500, 1000.

\+ Note that these are comparable with typical munitions expenditures

45 x 115 mm Multi-barrel rockets	= 250 Kg.
1 x 750 lb GB aircraft bomb	= 100 Kg.
2 Frogs or 1 Scud	= 500 Kg.

19. Downwind and Crosswind Positions of Personnel and Detector ++

Downwind metres	Crosswind metres	
500,600,700,800,900	0,50,100,200	Neutral and Inversion
1000,1100,1200,1300,1400	0,50,100,200,300	
2000,2100,2200,2300,2400	0,100,200,400,600	
3000,3100,3200,3300,3400	0,200,400,600,800	
4000,4100,4200,4300,4400	0,250,500,750,1000	
	0,100,200,400,600	Lapse
	0,200,400,600,800	
	0,400,800,1200,1600	
	0,500,1000,1500,2000	
	0,500,1000,2000,3000	

++ Note that approximate cloud widths corresponding to the Meteorological Categories are:-

Downwind distance metres	Cloud width, w metres, for Meteorological category Lapse (I)	Neutral (N)	Inversion (P)
500	400	150	100
1000	700	280	190
2000	1,300	530	350
3000	1,800	750	500
4000	2,300	1,000	650

RESULTS

20. The results are presented in Tables 4a, b, and in Figures 4 - 11. The calculated dosages are general for vapours of all agents, however they should be considered in relation to the toxic dosages given for the nerve agents in Table 1. Furthermore, while the detector characteristics C^*, t_r, are also general for vapours of all agents they should be related to the performance of the M8 nerve agent alarm as illustrated in Table 1 and Figure 2. It should be remembered that the dosage calculations are based on models of the real situation and are only expected to provide guidance as to likely events; magnitudes are probably only accurate to within a factor of two or three (6). In presenting the results, the scheme adopted is to select a standard set of conditions, viz. instantaneous point source of 500 Kg, neutral meteorological conditions with a 5 knot ($2.57 m.s.^{-1}$) wind, detector C^*, $0.1 mg.m^{-3}$ and t_r+t_m, 30 s, plot the dosage versus downwind distance relationship for this condition, and then show how the variables produce changes in this dosage/distance relationship.

21. Typical computer 'print-outs' are shown in Tables 4a, b. Table 4a illustrates Case 2a Table 3, with the detector on the cloud axis at position (x,y:500,0). Triggering occurs when the cloud centre has travelled 382 metres when t_c= 148,3 seconds: t_r+t_m is chosen to be 10 seconds. Dosages accumulated by troops are arranged in a matrix of downwind versus crosswind positions and are seen to be negligible; they are a consequence of the low value for t_r+t_m, despite the relatively high C^*, $0.5 mg.m^{-3}$. Table 4b illustrates Cases 2e,f,g Table 3, with the detector off the cloud axis at position (x,y: 500,150) failing to operate. Troops on the axis get the maximum possible agent dosage which decreases with increasing distance of troops downwind. The dosage also declines as troops move crosswind towards the cloud boundary; however, troops positioned 100-200 metres crosswind of the cloud axis accumulate an increasing dosage as they move downwind from 500 to 900 metre. The results obtained in a large number of 'print-outs'

of this type are summarised in Figures 4-11 and are further discussed below following the scheme outlined in paragraph 20 above. In these figures D^T and D^P represent total and partial dosages respectively and the subscripts to the dosages refer to the magnitude of the particular variables under consideration in the Figure under discussion.

22. Effect of Meteorological Category (Figure 4) If the limiting downwind distance for a given magnitude of hazard (assumed to be an $ICt_5 = 5$ mg.m^{-3}) is taken as a measure of the relative hazards corresponding to the main meteorological categories, the latter may be placed in the following order for magnitude of hazard:-

Inversion (> 20 Km)> Neutral ($\sim$ 15 Km) Lapse ($\sim$2 Km).

Conditions of strong lapse and strong inversion were assumed in the calculations and there is a continuous gradation of hazard possible within this category range. The use of detectors greatly reduces the hazard although dosages > ICt_5 may still be accumulated in the range 0.5 to 1.0 Km under neutral and inversion conditions.

23. Effect of Wind Speed (Figure 5) Total dosage decreases with increase in wind speed due to the decreased residence time of personnel in the agent cloud. However, partial dosages are much increased because of the higher agent concentration reaching the personnel. In general this effect will become more serious the steeper the gradient of concentration at the front boundary of the cloud, the higher the value of C^*, and the longer the delay in masking.

24. Effect of Source Strength (Figure 6) Dosage is directly proportional to source strength, as shown by Eqn.8 in Appendix 1, and this is well illustrated by the total dosage lines in the figure. The close proximity of the individual partial dosage lines indicate that (at least for a detector with C^* 0.1 mg.m^{-3}, $t_r + t_m$ 30 s) source strength is of minor importance in

deciding the 'off target' hazard to personnel using a detector; for them, the hazard range is again 0.5 to 1.0 Km.

25. Effect of Masking Time (Figure 7) The wide spread of the partial dosage lines emphasises the importance of masking time. With, $t_r + t_m = 90$ s., the hazard at 1 Km is not much less than a total dosage hazard and an ICt_5 may be accumulated out to 2-3 Km. On the other hand, if $t_r + t_m = 10$ s. the hazard is reduced to negligible proportions. Clearly, the hazard due to slow masking would be further increased at high wind speed.

26. Effect of Critical Detector Concentration (Figure 8) The present results indicate that C^* is of minor importance in comparison with masking time; change of C^* from 0.01 mg. m^{-3} to 1.0 mgm^{-3} (i.e. a factor of 100) has less effect on the partial dosages accumulated by personnel than an increase in $t_r + t_m$ from 30 to 90 seconds. (i.e. a factor of 3). Note however the divergence of the partial dosage lines with increase in downwind distance; this indicates that C^* will increase in importance for (wide) clouds with low concentration gradient at the boundary and low peak concentration i.e. as produced by area coverage with multiple small munitions.

27. Crosswind placing of Detector (Figure 9) The troops are assumed to be in the worst position, on the cloud axis, and are liable to receive the maximum possible dosage at their downwind distance if the detector is slow or fails to operate. Although the partial dosage lines are drawn through only two points in each case it is expected that they will be linear as shown. At 600 metres spacing the total dosage will be accumulated out to a range of 3 Km. Clearly, if troops and alarms are on the same crosswind line (equidistant from an upwind source) it is inadvisable that they be at distances much greater than 100 metres from their detectors; the range of maximum hazard would thus remain 0.5 to 1 Km from the source.

28. Crosswind position of Troops (Figure 10) The detector is assumed to be in its best position, on the cloud axis, and the troops are positioned crosswind at y co-ordinates 0,50,100 metres.

As expected, the partial dosages decline the closer the troop positions are to the cloud boundary.

29. Downwind positioning of Troops relative to the Detector (Figure 11) This figure illustrates the effect of downwind positioning of troops (upwind positioning of the detector) under conditions of low and high wind speeds (5 and 15 knots respectively). Both troops and detector are assumed to be on the cloud axis. As discussed earlier (paragraph 23) the total dosage at a point falls as the wind speed rises - see graphs indexed $D^{T}_{N,5}$ and $D^{T}_{N,15}$. Under conditions of low wind speed, with the other variables (meteorological, source, detector) as specified in Figure 11, the partial dosages experienced with zero upwind placement of the detector ($D^{P}_{N,50}$) will be hazardous over the range 0.5 to 1.0 Km. An upwind placement of 100 metres will entirely eliminate this hazard. Under conditions of high windspeed (15 knots), an upwind placement of 100 metres will reduce but not eliminate the hazard, and if masking times $t_r + t_m$ are lengthened to 90 seconds an upwind placement of 400 metres will not provide adequate warning time. These statements are further illustrated by the dosage values given below.

Detector position, m.		500	1000	2000	3000	4000
Dosages, $mg.min/m^{-3}$)	a	0	0	0	0	0
at troop positions)	b	4	0.3	0.1	0	0
	c	200	-	11	3	1

a, 100 metres downwind, $t_r + t_m$ = 30 seconds.

b, 200 " " , " " " "

c, 400 metres downwind, $t_r + t_m$ = 90 seconds.

30. Recommended Detector Emplacement Both upwind emplacement and crosswind separation of detectors require consideration. With regard to the former it must be remembered that the greater the detector-troop distance the higher the probability that a cloud will fail to trigger the detector while producing a significant dosage to troops downwind (Case 2g, Table 3). It is clear that the nerve agent detector, M8, presently expected to enter service with UK forces ($t_r \sim 30$ s, $C^* 0.5$ mg.m^{-3} for GB) will not give sufficient warning to eliminate entirely the hazard to troops even with upwind detector emplacement; the most hazardous conditions being those with high wind speeds. Without further detailed analysis it is not possible to recommend the optimum detector emplacement. With the present information, a sensible arrangement would appear to be that a single detector should be emplaced about 100 metres upwind of troops, and if two or more detectors are available they should be emplaced 100 to 200 metres upwind (reference para.29) at a crosswind spacing of $\sim$ 200 metres (reference para.27). These spacings may be compared with those recommended in earlier papers i.e.

Upwind positioning $\leqslant$ 500 metres, crosswind spacing $\sim$ 220 metres(8).
" " $\sim$ 150 " , " " $\sim$ 330 " (9).

31. Relative importance of Detector Characteristics The aim of the present study was to investigate the use of a local detector in relation to 'off target' attacks. Such attacks were considered to be those due to vapour or aerosol originating from munitions bursting uptind of a defended position, or to vapours drifting downwind from an area contaminated with persistent agents (reference para. 8 and Figure 1). In general, in the former case troops would be subjected to a high concentration of vapour for a short time, and, in the latter case to a low concentration for a long time; the method of the present study effectively limits the study and its conclusions to the former case. The conclusions with respect to detector characteristics are:-

(i) That trigger and response times ($t_c + t_r$) and the subsequent masking time t_m - giving the total exposure

time T_e - are the most important factors in determining the dosages accumulated by troops.

(ii) That providing T_e is minimised, concentration sensitivities ranging from 0.01 to 1.0 $mg.m^{-3}$ are acceptable.

However, if it is required to detect vapours from persistent agents and to use the detector as either a confirmation monitor or a contamination monitor, then the concentration sensitivity will be important. A theoretical study on the use of the Residual Vapour Detector (RVD) in these latter rôles (10) has shown that a concentration sensitivity of $C^* \sim 0.01\ mg.m^{-3}$ is acceptable for monitoring purposes. Thus, it may be concluded that in order to counter the present nerve agent threat an automatic local detector is required to detect agent concentrations $\leqslant 0.01\ mg.m^{-3}$ with an alarm responde time $t_r \leqslant 10$ seconds; this instrument would also fulfil the requirements for chemical monitoring.

CONCLUSIONS

32. (i) The characteristics required by an automatic local detector for use in 'off target' attacks to detect chemical agent vapours and aerosols from munitions bursting upwind are:-

Response time $t_r \leqslant 10$ seconds.

Critical Detector Sensitivity 0.01 to 1.0 $mg.m^{-3}$.

(ii) If the detector device is also required to fulfil the roles of chemical monitoring then the required characteristics become:-

Alarm Response time $\leqslant 10$ seconds.

Critical Detector Sensitivity $\leqslant 0.01\ mg.m^{-3}$.

(iii) The nerve agent detector, M8, will not give sufficient warning to eliminate entirely the hazards from nerve agents in the field. However, a significant reduction in hazard may be achieved if it is used intelligently.

(iv) Without further detailed analysis it is not possible to recommend an optimum detector emplacement. Present information indicates an upwind emplacement of 100 to 200 metres, and, if more than one detector is available, a crosswind detector spacing of $\sim$ 200 metres.

(v) The most hazardous meteorological conditions occur when there is a zero or positive temperature gradient and high wind speed (may be 15 knots under Neutral conditions).

(vi) In order to minimise the hazard from 'off target' attacks it is essential to minimise the masking time.

RECOMMENDATIONS

33. Assessments should be made of probable casualty levels to troops relying on automatic local detectors who are subjected to 'off target' attacks with nerve agents; particular attention should be paid to the following means of agent delivery, (a) single large source e.g. an aircraft bomb, (b) multiple small sources e.g. multi-barrelled rocket launcher, (c) area contamination by coarse spray.

REFERENCES

(1) U.S.A. Combat Development Command Report. "Mandrake Root". May 1968.

(2) N.B.C. Defence Training Volume I, Pamphlet 5. Defence N.B.C. School, Winterbourne Gunner.

(3) NATO Document AC/196(Chem)WP/15.

(4) NATO Document AC/196(WP/2)D/2. Evaluation Criteria for Local Detector, 22nd Oct. 65.

(5) 020922/1G. Defence N.B.C. School, Winterbourne Gunner. The US/M8 Alarm System. Part.1. Concept of Use and Scale of Issue. 7. Aug. 69.

(6) Meteorological Office Scientific Paper No. 24. An Atmospheric Diffusion Slide Rule. C.E. Wallington.

(7) Atmospheric Diffusion. Chapter 5. F. Pasquill. D.van Nostrand 1961.

(8) C.D.E. Technical Paper No.4. An Analysis of the Sensitivity Requirements for a Near-Infrared Early Warning Device.

(9) U.S. Army C.D.C. Study. CBR-75(U). Concept Paper on U.S. Army Chemical Agent Detection and Warning Functions. Sept. 1968.

(10) C.D.E. Technical Paper No.19. The Hazard which accompanies unmasking in a Contaminated Area with Toxic Agent Vapour Concentration below Detection Level.

Table.1. Toxicological Exposure Times and Detector Response Times for Nerve Agents

Agent Concentration $mg.m^{-3}$		100	10	1.0	0.1	0.01	0.001
Toxicological Exposure Times in minutes.*			LCt_{50}	ICt_5		ECt_{90}	Detoxification levels.
	VX		5	2.5		<2 ↑	
	GB		10	5		100 ↑	
	GD		5	5		100 ↑	
Response Times in minutes** NATO Criteria	VX		.03	0.5			
	GB		.03	0.5	1		
	GD		.03	0.5	1		
Response Times in minutes US-M8	VX		-	0.8	2.5	Present limit	
	GB		0.13	0.3	1.3		

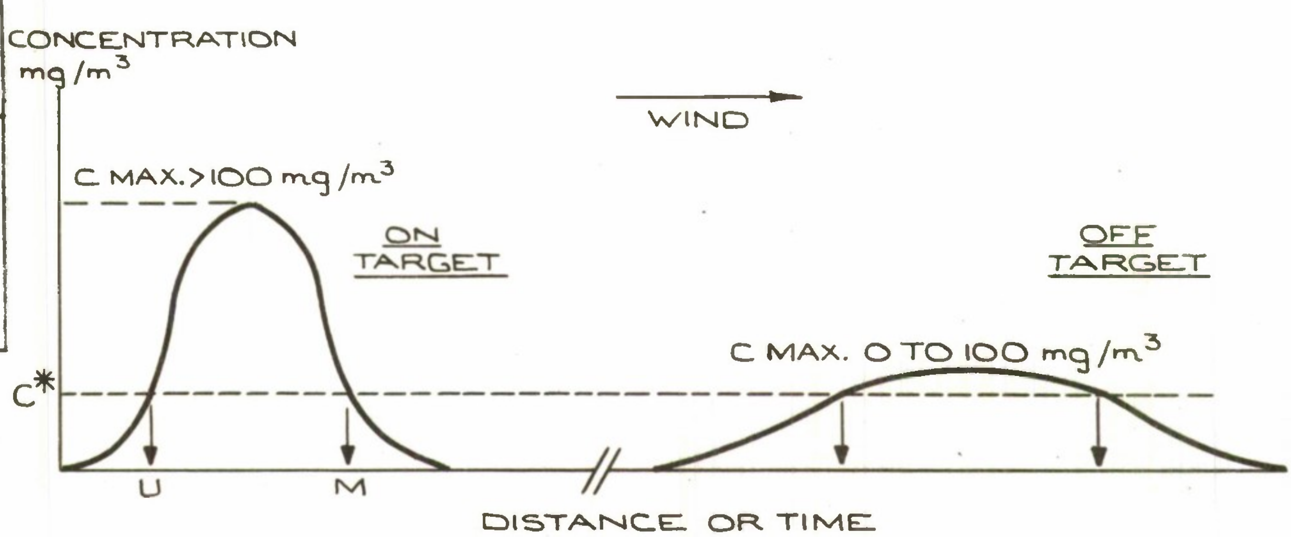
* Dosage = Concentration x time; the ECt_{90} value refers to miosis; all dosages in this table refer to a breathing rate of 20 l. min^{-1}.

** Desirable response times.

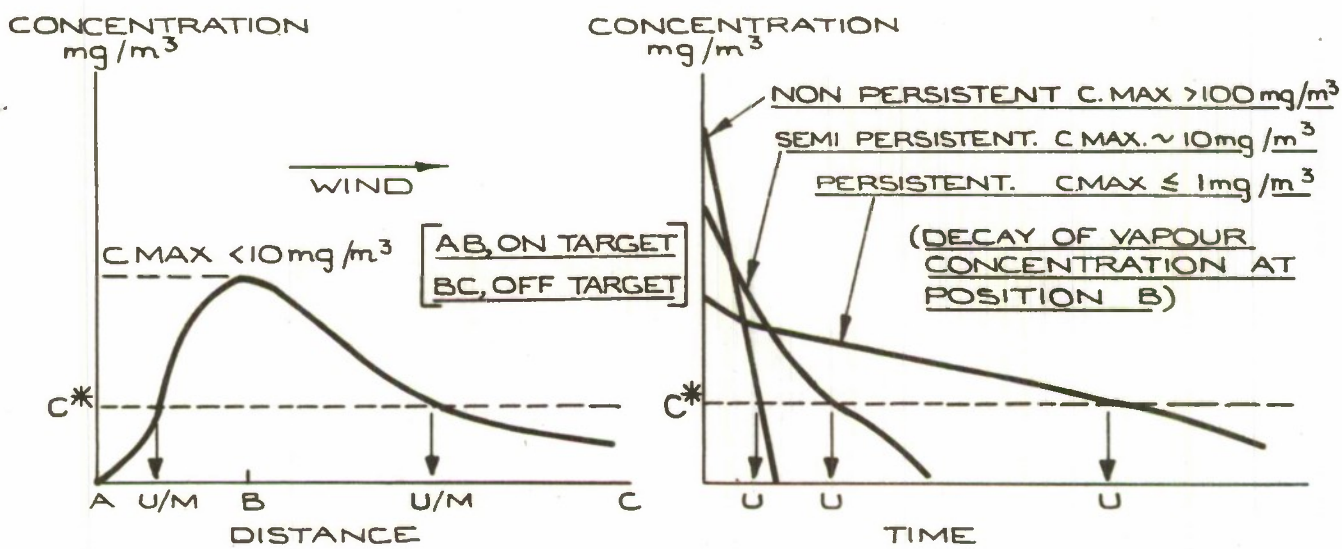
Table 2. Concepts of the Use of Local Detectors

	Agent type	Agent form	Agent Concn.*	Hazard location	Hazard duration	Defence
1.	Non-persistent	Vapour	<100mg/m^3	On target	Minutes	1A drill. Local detector confirms.
			0-100mg/m^3	Off target	Minutes	Broadcast warning OR Local detection
2.	Persistent	Spray	< 10 g/m^2	On target	Hours/days	Detector paper.(spray <50μ)
		Vapour	< 10mg/m^3	On target	Hours/days	Detector paper + Local detector
		Aerosol	< 10mg/m^3	Off target	Minutes	Local detector.
		Vapour	< 10mg/m^3	Off target	Hours/days	Local detector.

* The values given only indicate possible agent concentrations.



(i) CLOUD OF NON PERSISTENT AGENT RELEASED BY AN INSTANTANEOUS POINT SOURCE.



(ii) CLOUDS OF PERSISTENT AGENT VAPOUR RELEASED BY A CONTINUOUS AREA SOURCE.

C*, DETECTOR SENSITIVITY

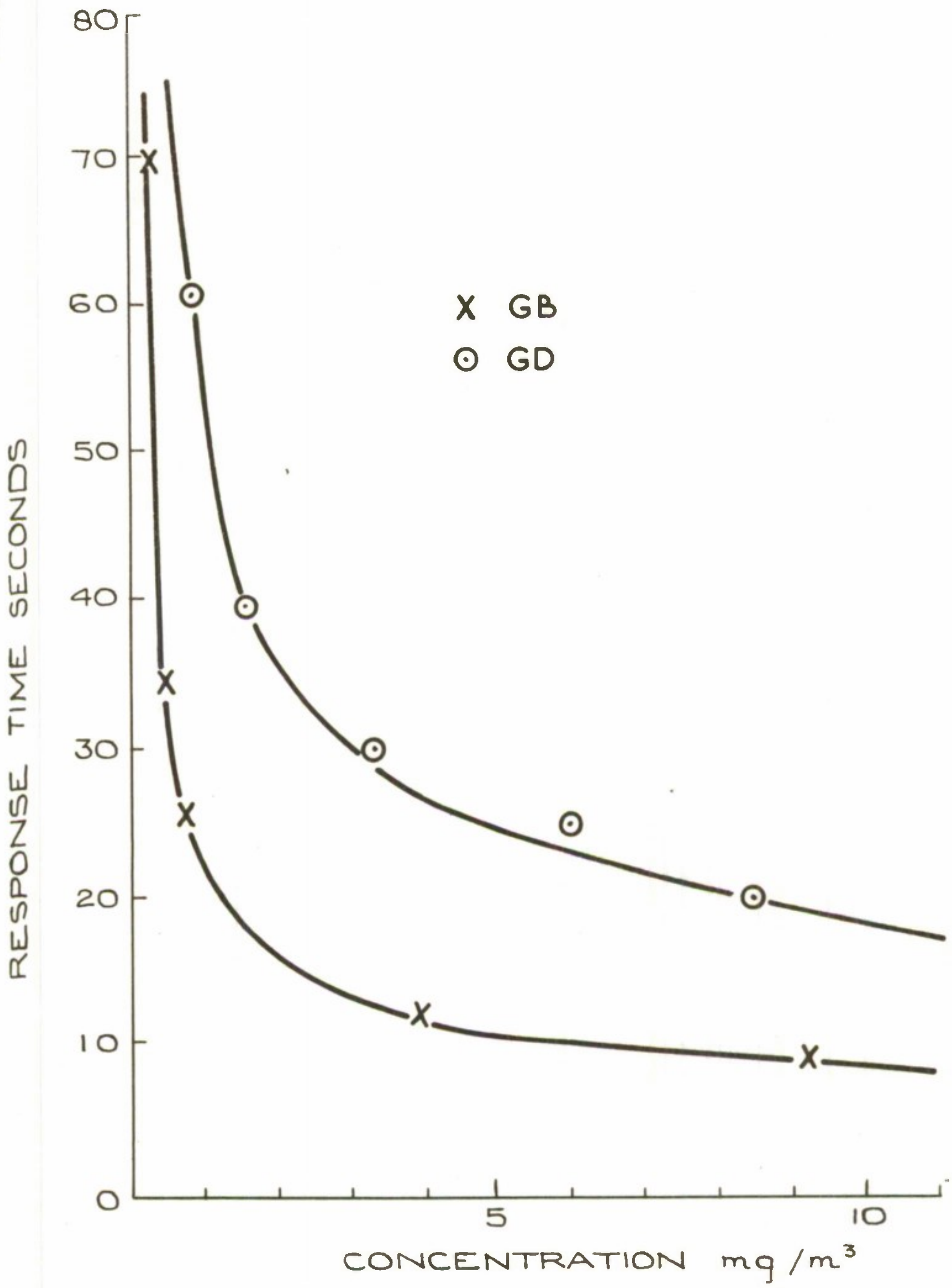
M, MASK - IA DRILL, BROADCAST WARNING, LOCAL DETECTOR, (RVD)

U., UNMASK - RVD, (LOCAL DETECTOR)

HAZARDS FROM CHEMICAL AGENTS IN ON AND OFF TARGET ATTACKS

FIG 1

TP 18 | PT 5867



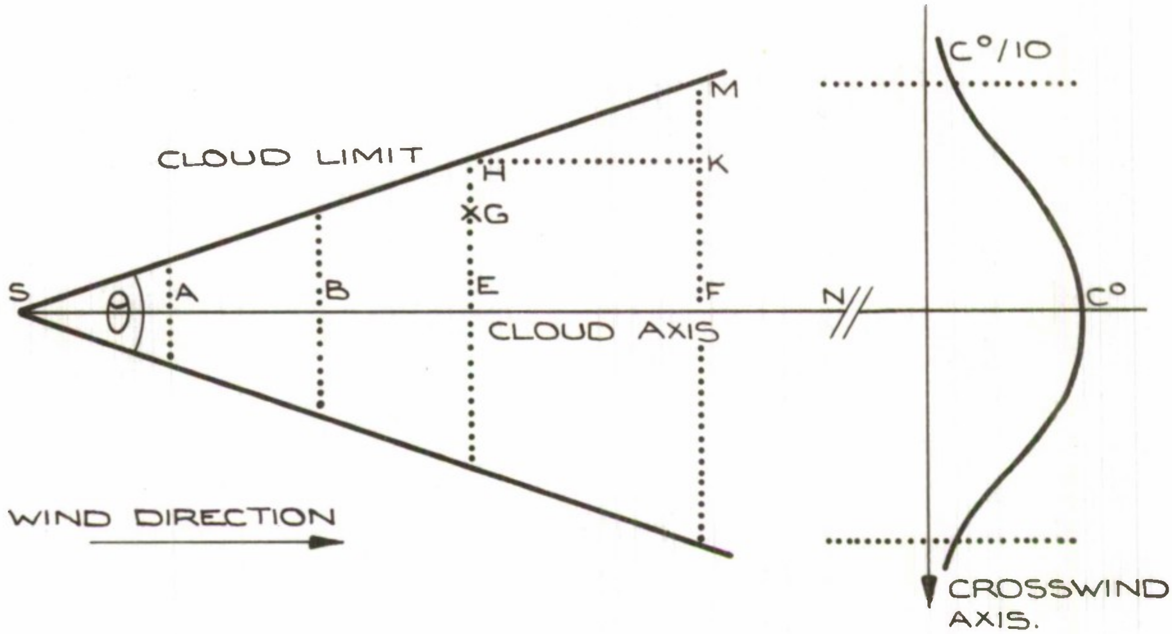
M8 DETECTOR CHARACTERISTICS.
(REF PTN./TD 1090/7034/68)

FIG.2

Table 3. Dosages received by troops positioned as indicated in Fig.3.

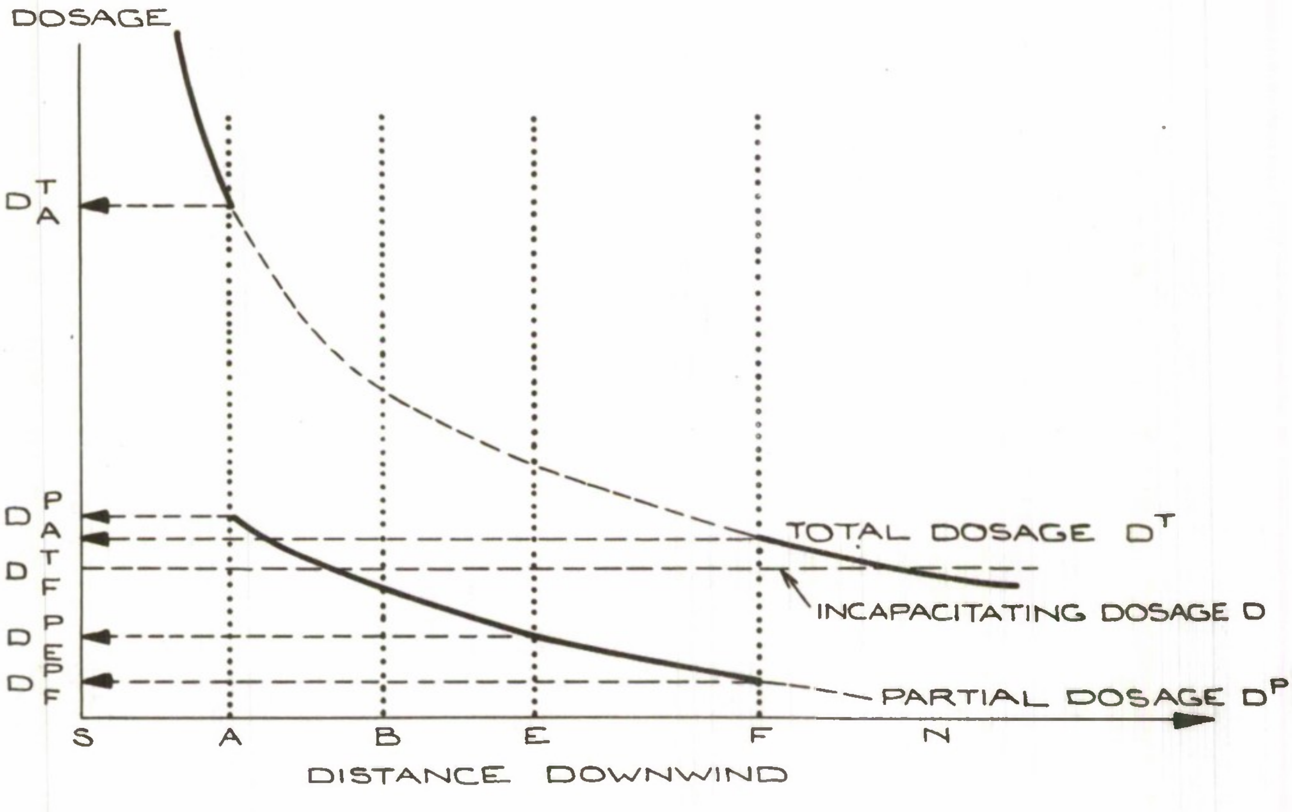
Case No.	Positions Troops	Detector	Dosage mg.min.m^{-3}	Concentration mg.min.m^{-3}	Remarks
1.	<A	<A	$\geq D_A^T$	$\geq C_A^o$	On cloud axis
2a	(A,B (E,F	(A,B (E,F	$D^P_{A,B,E,F.}$	C^o	) Detector on cloud axis.
2b.	B	B	D^*	C_B^o	)
2c.	G,H	E	$<D_E^P$, 0	C^o E	)
2d.	E	B	$<D_E^P$, $\rightarrow 0$.	C_B^o	)
2e.	E	G,H	$>D_E^P$, $\rightarrow D_E^T$	C_G,0	) Detector off cloud axis.
2f.	G,H	G.H	$<D_G^P$, $\rightarrow 0$	C_G,0	)
2g.	K	H	D_K^T	0	)
3.	$\geq$F	$\geq$F	$\leq D_F^T$	$\leq C_F^o$	On cloud axis.

TP 18 | PT 5868



POSSIBLE POSITIONS OF SOURCE S, TROOPS, AND DETECTOR, IN CLOUD PATH

FIG. 3a



DOSAGE / DISTANCE RELATIONSHIP IN CLOUD PATH

FIG. 3b

Table 4a. Dosages received at various points after triggering of the alarm.

Source

Instant point source of strength 500,000 Grammes

Meteorology

Met. Category N

Windspeed 2.574 metres/second

Alarm

Critical concentration is 0.50 mg/m_3, and position is 500 metres downwind and 0 metres crosswind of the source

Alarm is triggered after 148.3 seconds, when cloud has travelled 382 metres, and the troops are unprotected for a further 10 seconds while masking

Dosages accumulated before masking in $mg.min/m_3$.

D/W Distance from source (metres)	C/W distance from source (metres)				
	0	50	100	150	200
500	1.4	0.5	0.0	0.0	0.0
600	0.0	0.0	0.0	0.0	0.0
700	0.0	0.0	0.0	0.0	0.0
800	0.0	0.0	0.0	0.0	0.0
900	0.0	0.0	0.0	0.0	0.0

Table 4b. Dosages received at various points after triggering of the alarm.

Source

Instantaneous point source of strength 500000 grammes

Meteorology

Met. category N

Windspeed 2.574 metres/second

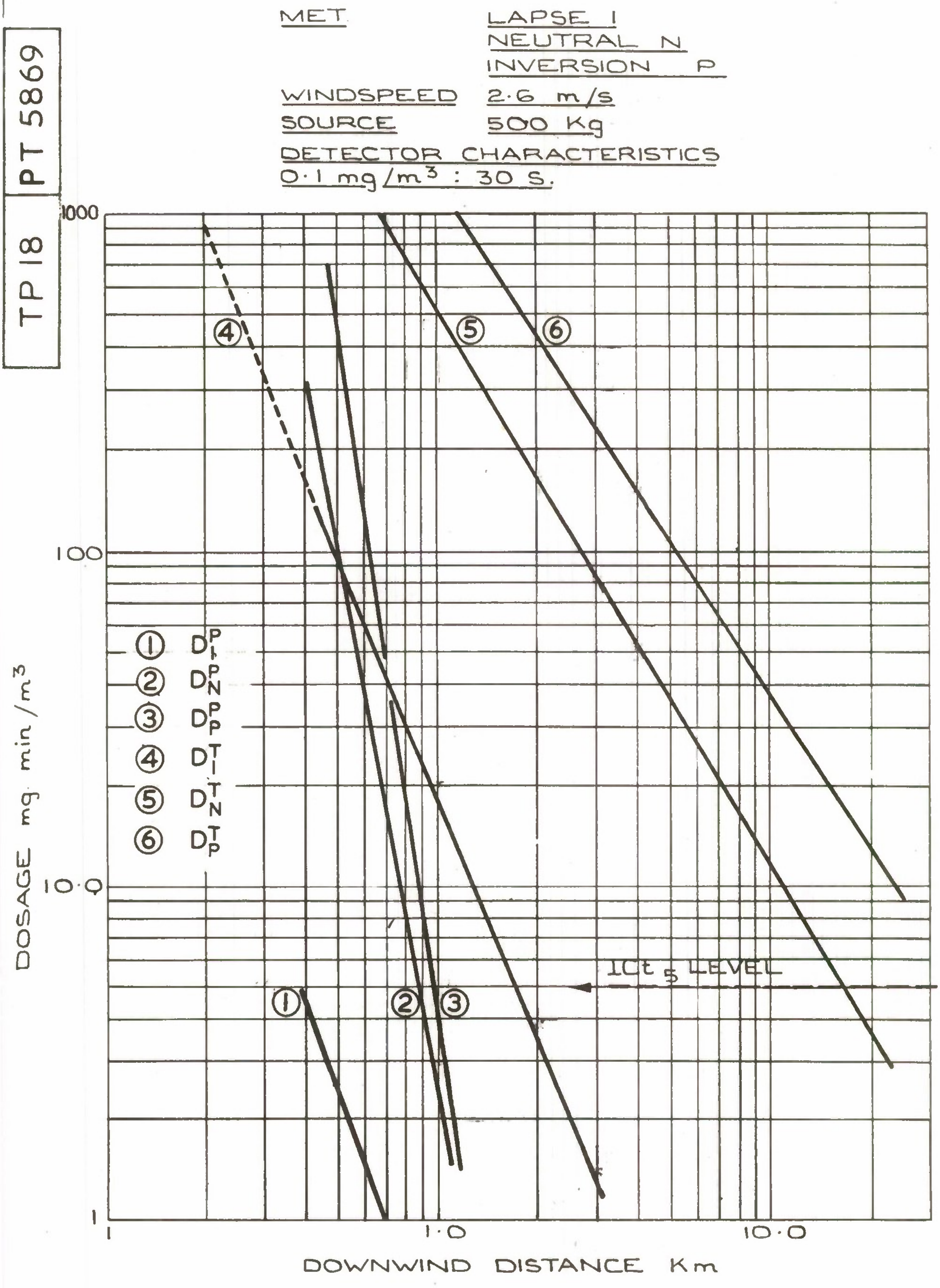
Alarm

Critical concentration is 0.50 mg/m_3, and position is 500 metres downwind and 150 metres crosswind of the source

Alarm is not triggered

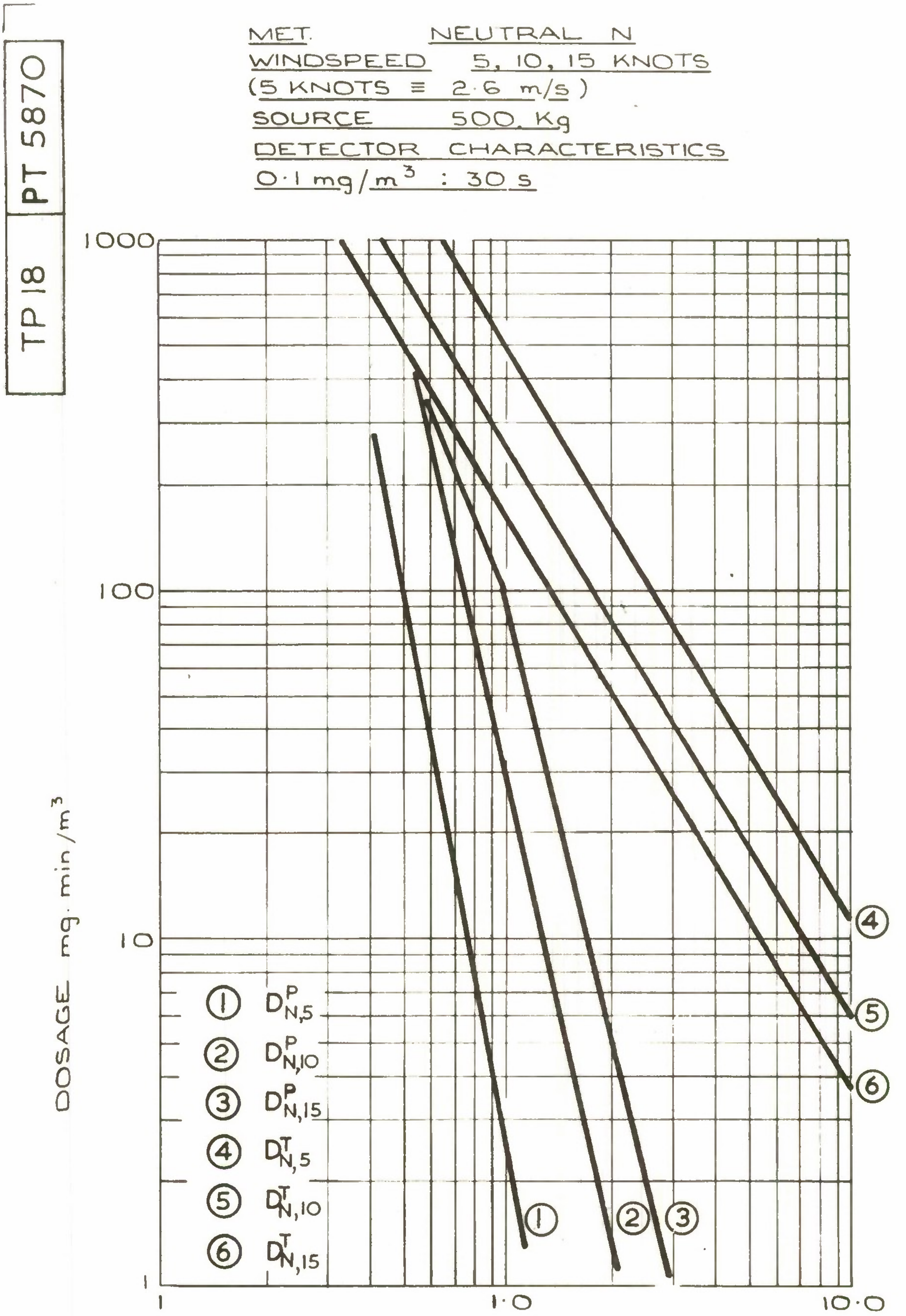
Dosages accumulated before masking, in mg.min/m_3.

D/W Distance from source (metres)	C/W distance from source 9metres)				
	0	50	100	150	200
500	1647.7	591.8	27.4	0.2	0.0
600	1217.1	582.8	64.0	1.6	0.0
700	942.1	539.6	101.4	6.3	0.1
800	754.6	487.1	131.0	14.7	0.7
900	620.4	435.6	150.7	25.7	2.2



TOTAL D^T AND PARTIAL D^P DOSAGES v DOWNWIND DISTANCE FOR METEOROLOGICAL CATEGORIES I, N, P,.
(TROOPS AND DETECTOR ON CLOUD AXIS)

FIG. 4

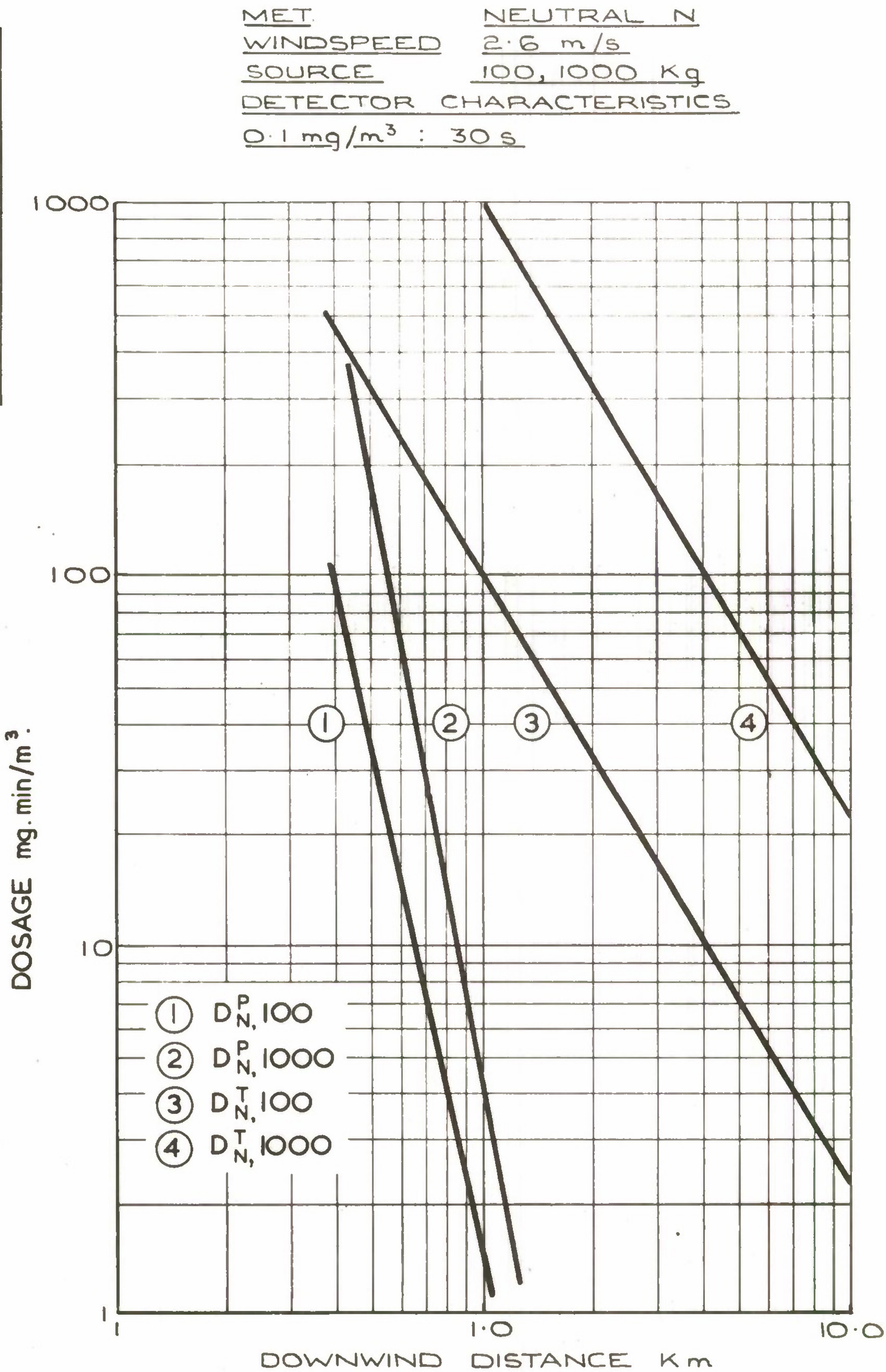


TOTAL D^T AND PARTIAL D^P DOSAGES V DOWNWIND DISTANCE FOR WINDSPEEDS OF 5, 10, 15 KNOTS.

(TROOPS AND DETECTOR ON CLOUD AXIS)

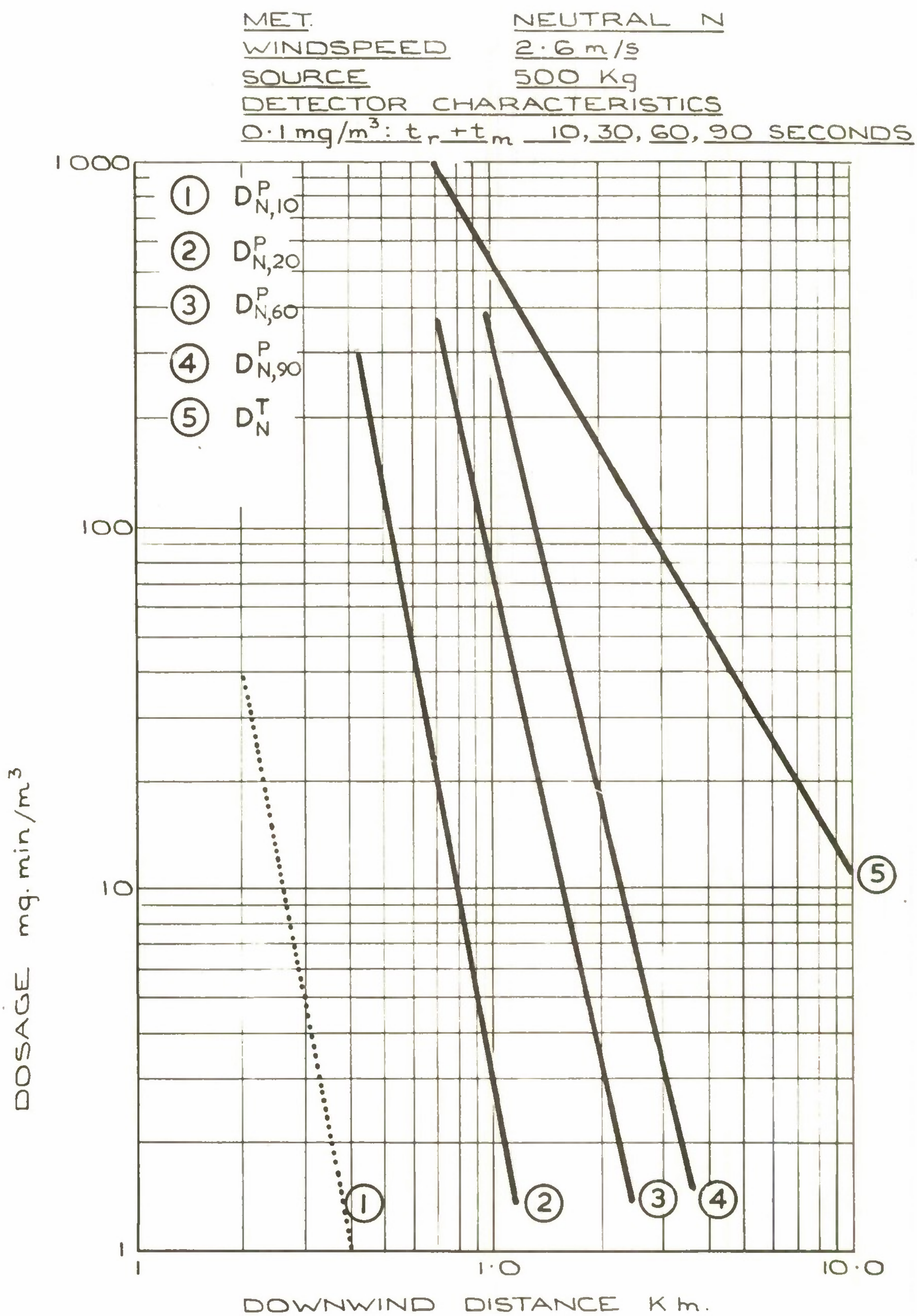
FIG. 5

TP 18 | PT 5871



TOTAL D^T AND PARTIAL D^P DOSAGES v DOWNWIND DISTANCE FOR SOURCE STRENGTHS OF 100, 1000 Kg (TROOPS AND DETECTOR ON CLOUD AXIS.)

FIG. 6

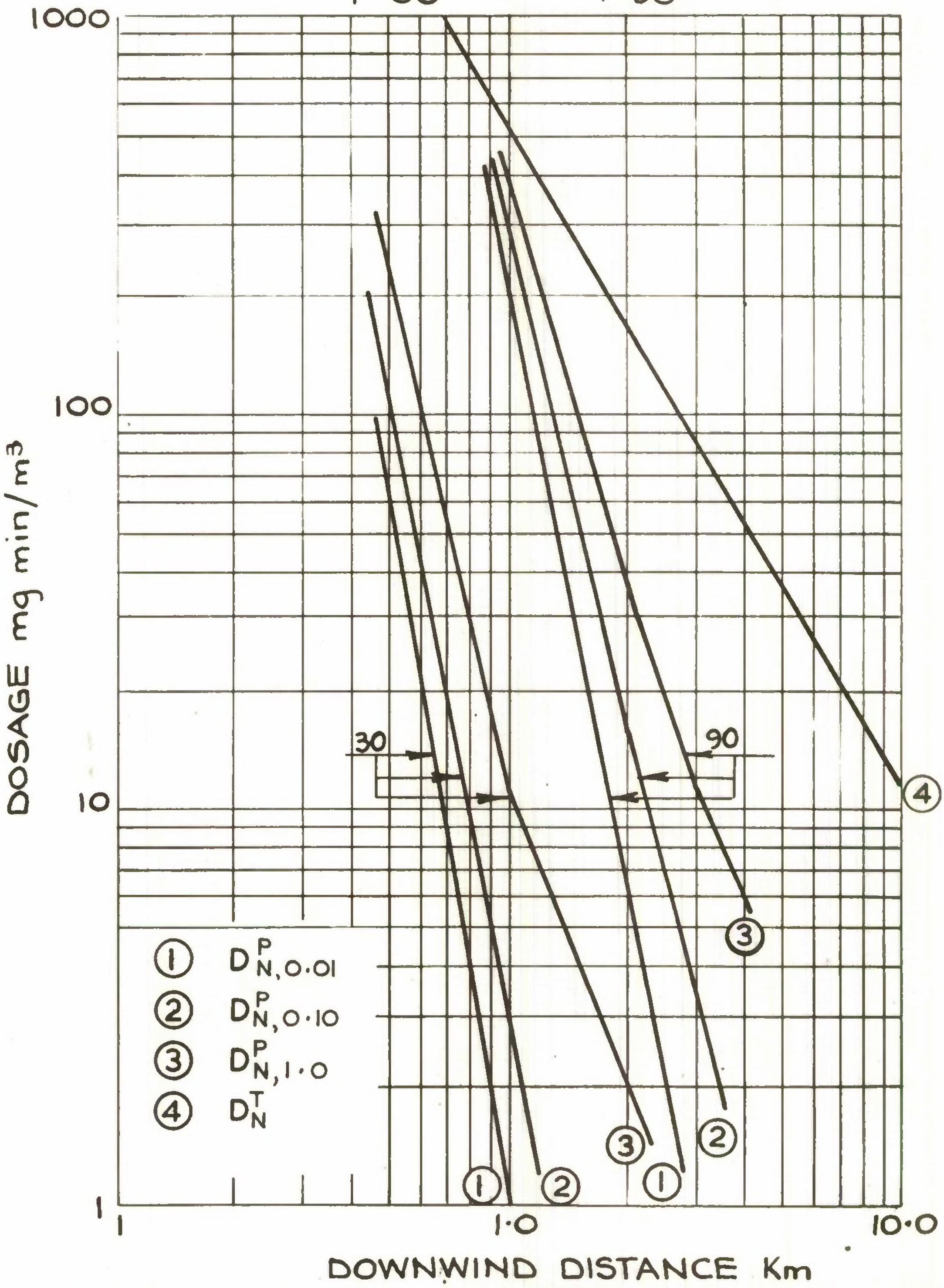


TOTAL D^T & PARTIAL D^P DOSAGES v DOWNWIND DISTANCE FOR (RESPONSE + MASKING) TIMES OF 10, 30, 60, 90 SECS.. (TROOPS AND DETECTOR ON CLOUD AXIS).

FIG. 7

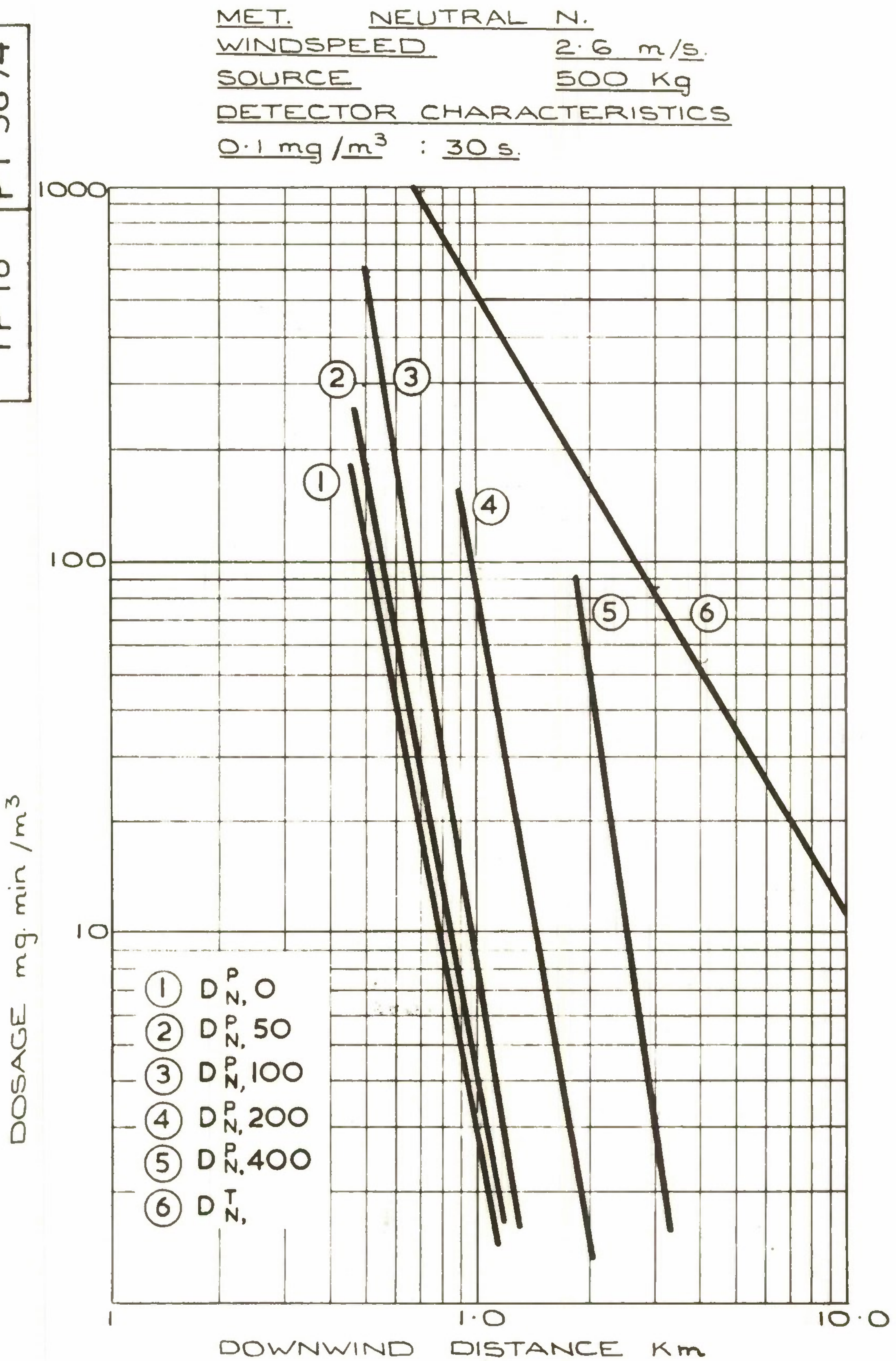
TP 18 | PT 5873

MET NEUTRAL N
WIND SPEED 2·6 m/s
SOURCE 500 kg.
DETECTOR CHARACTERISTICS
0·01 | 30
0·10 mg/m³ | SECONDS
1·00 | 90



TOTAL D^T AND PARTIAL D^P DOSAGES v DOWNWIND DISTANCE FOR (RESPONSE + MASKING). TIMES OF 30, 90 SECONDS AND CRITICAL DETECTION CONCENTRATIONS OF 0·01, 0·1 AND 1·0 mg/m³. (TROOPS AND DETECTOR ON CLOUD AXIS)

FIG.8.



TOTAL D^T AND PARTIAL D^P DOSAGES v DOWNWIND DISTANCE FOR CROSSWIND PLACINGS OF THE DETECTOR, 0, 50, 100, 200, 400 METRES (TROOPS ON THE CLOUD AXIS)

FIG. 9

TP 18 PT 5875

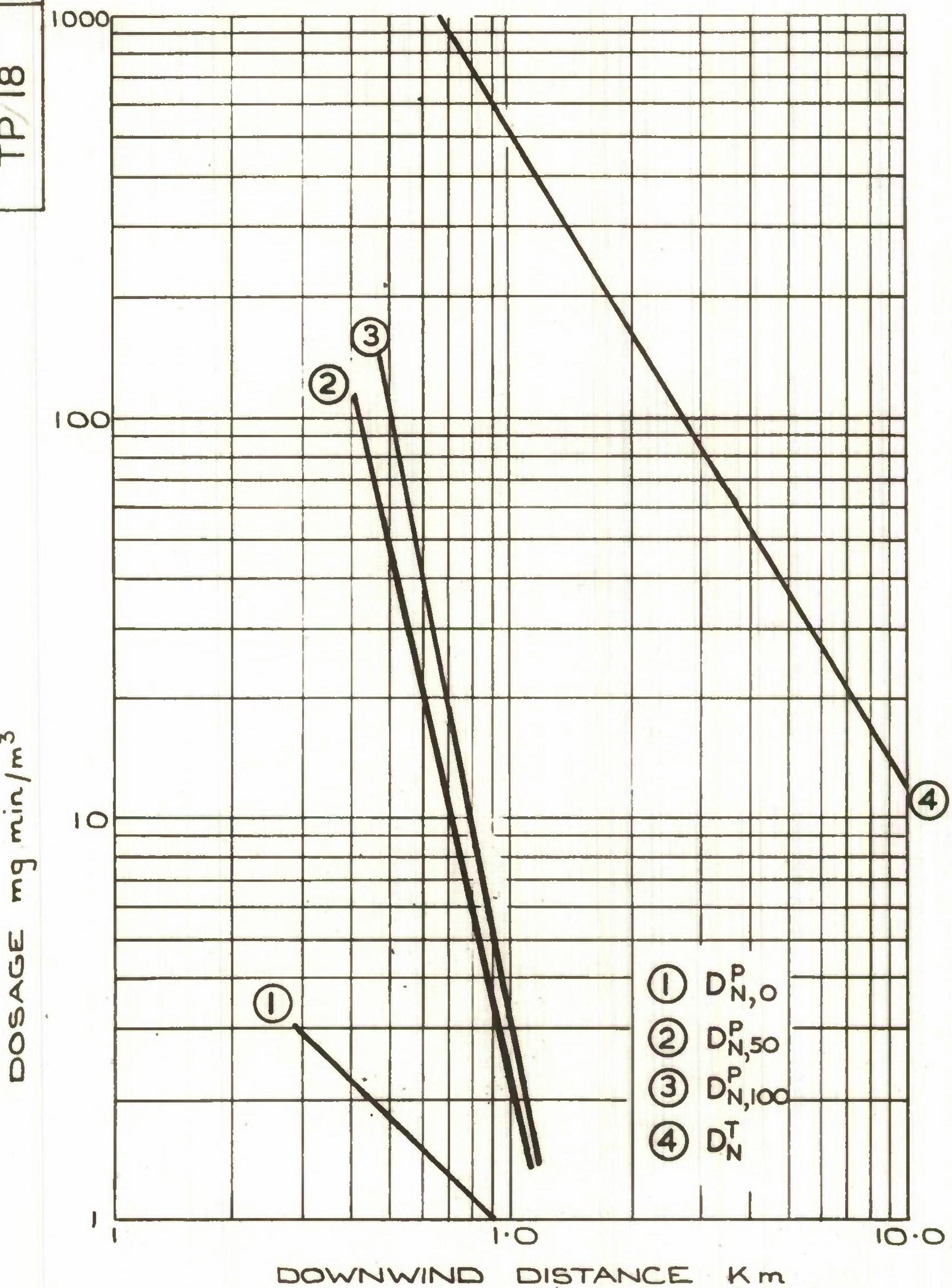
MAT. NEUTRAL N.

WINDSPEED 2·6 m/s

SOURCE 500 Kg

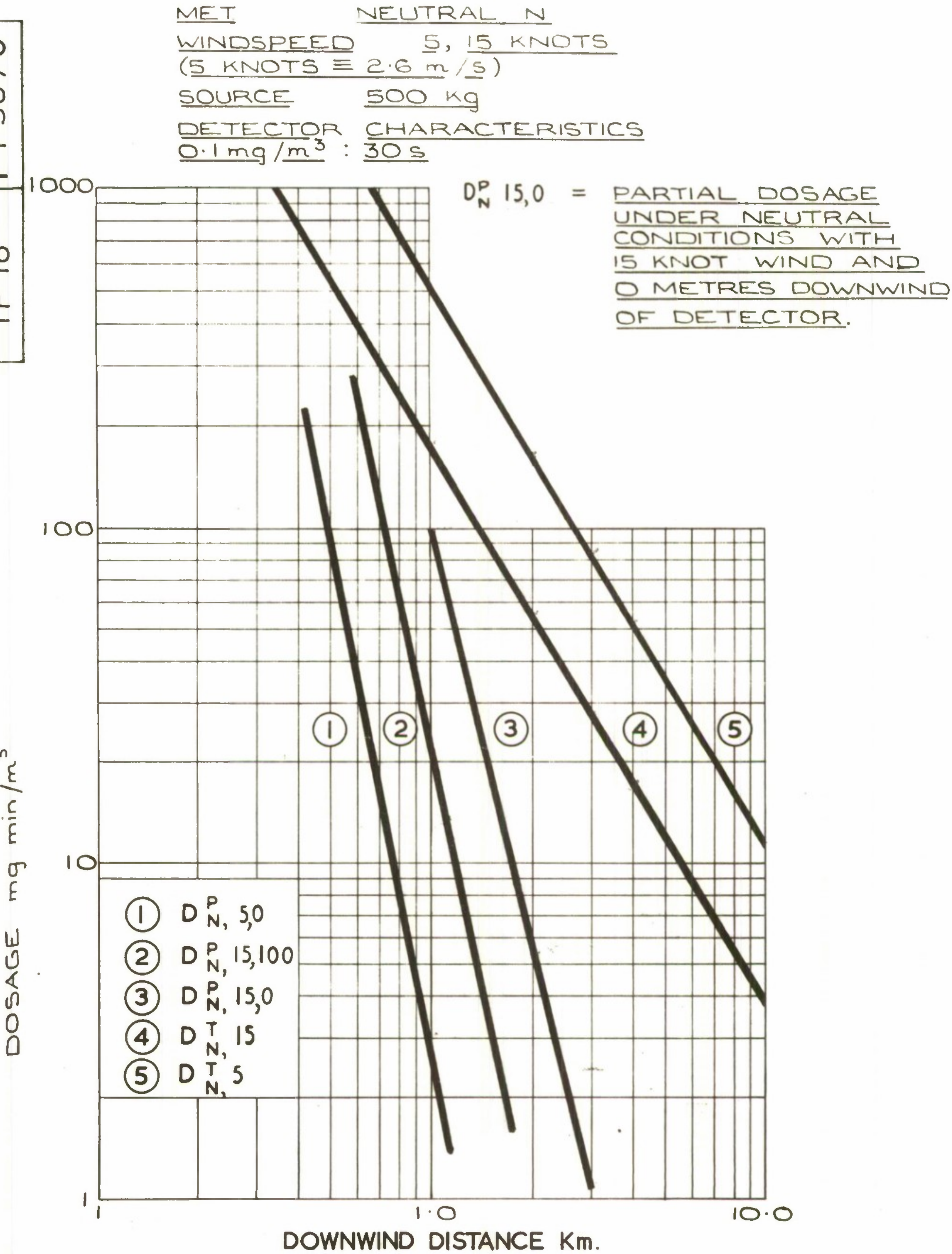
DETECTOR CHARACTERISTICS

0·1 mg/m³ : 30 s.



TOTAL D^T AND PARTIAL D^P DOSAGES v DOWNWIND DISTANCE FOR CROSSWIND POSITIONS OF TROOPS. 0, 50, 100 METRES. (DETECTOR ON THE CLOUD AXIS)

FIG. 10



TOTAL D^T AND PARTIAL D^P DOSAGES v DOWNWIND DISTANCE AT POSITIONS 0 AND 100 METRES DOWNWIND OF THE DETECTOR (TROOPS AND DETECTOR ON CLOUD AXIS)

FIG. 11

Appendix 1. Equations used for the calculations of partial dosages

1. Cloud Diffusion Model.

The agent concentration C_{xyt} at ground level at co-ordinates (x,y) and at time (t) after release from an instantaneous point source is assumed to be a normal Gaussian distribution as follows:-

$$C_{xyt} = C^o_{xyt} \exp - K\left[\frac{(x - vt)^2 + y^2}{w^2}\right] \qquad \ldots\ 1.$$

If the cloud travel at wind velocity (v), then after time (t_1), its centroid will be at (x_1), and it will have attained height (h_1), and width (w_1),

Exponential constant, K = 4 ln 10

Centroid position, $x_1 = vt_1$ .... 2.

Concentration at centroid, $C_1{}^o = 5Q/_{h_1 w_1{}^2}$ .... 3.

$$C_{xyt,} = C^o_1 \exp -K\left[\frac{(x-vt_1)^2+y^2}{w_1{}^2}\right] \qquad \ldots\ 4.$$

2. Exposure Time

If the detector is at co-ordinates (x_2,y_2) then $C_{x_2y_2}$ may be calculated from Eqn.4, and when:-

Critical detector concentration, $C^* = C_{x_2y_2}$ .... 5.

Detection time, $t_c = t_1$ .... 6.

Then by definition the exposure time of personnel to the agent is given by:-

$$T_e = t_c + t_r + t_m \qquad \ldots\ 7.$$

3. Accumulated Dosages

If the personnel are at co-ordinates (x_3y_3) then the dosage received before masking is:-

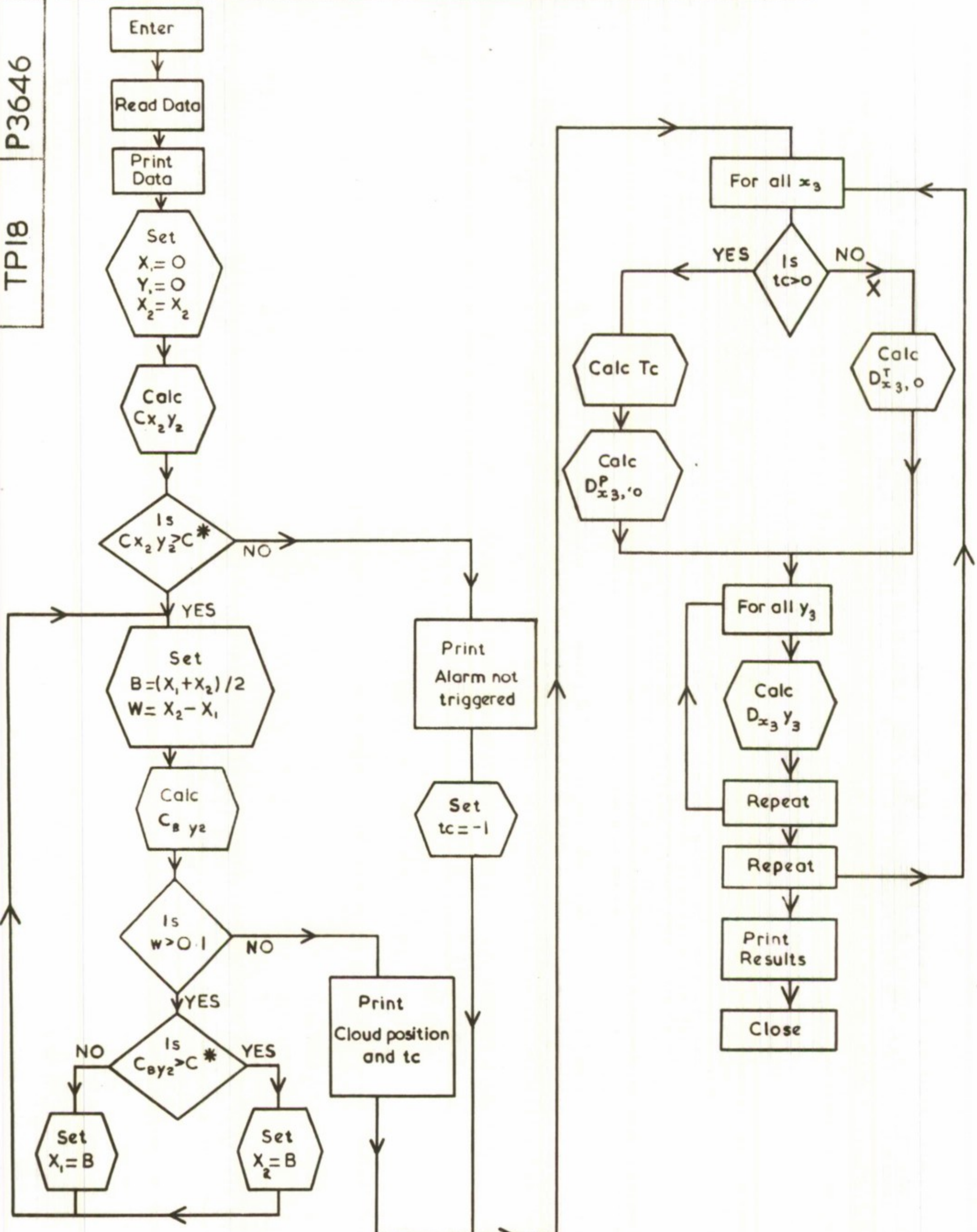
$$D^P_{x_3y_3}\ Te = \frac{250Q}{3}\int_o^{Te} \frac{1}{hw^2} \exp\text{-}K\left[\frac{(x_3-vt)^2 + y_3{}^2}{w^2}\right] dt \qquad \ldots\ 8.$$

4. Stages in Calculations

(a) Calculate the position of the cloud centroid when the agent concentration at the alarm is C^*. An 'interval bisecting' method is used in which successive values of $C_{x_2y_2}$ are calculated by means of Eqn. 4 (Appendix 1) and compared with C^*; when these values are equal $t_c = t_1$ Eqn.6., and the total exposure time of personnel T_e is given by Eqn. 7.

(b) Calculate the dosages at selected troop positions x_3y_3 for the known exposure time T_e by applying Simpson's rule to integrate Eqn.8.

APPENDIX 2. FLOW CHART FOR COMPUTER PROGRAMME.



CHAPTER 0. CALCULATION OF POSITION OF CLOUD CENTROID AND OF DETECTION TIME t_c.

CHAPTER 2. CALCULATION OF ACCUMALATE DOSAGES.

TITLE
DOSAGES ACCUMULATED BEFORE AND AFTER AN ALARM IS TRIGGERED.

```
CHAPTER2
A>15
C>10
D>10
E>10
F>10
G>10
W>100
X>2
Y>2
Z>100
1)Z=Z+U
N=xINTPT(Dn+0.5)
M=xINTPT(Fn+0.5)
R=1(1)M
x7(200+R)WR,1
G=xLOG(WR)
Wn=xEXP(DIG)
Vn=CIWn
JUMP9,Z>U
Hn=xEXP(EIGG+FIG)
Hn=GIHn
Y=xDIVIDE(50A,VHnVn)
JUMP10
9)A7=0
Xn=Z
B=VXn
A13=xLOG(B)
Wn=xEXP(2DIA13)
Wn=CICIWn
Hn=xEXP(EIA13A13+FIA13)
Hn=GIHn
A15=WR-B
A14=xEXP(A15A15F/Wn)
Yn=xDIVIDE(250A14A,3HnWn)
A2=Yn
A3=Z/12
S=1(1)3
B=3SA3V
A13=xLOG(B)
Wn=xEXP(2DIA13)
Wn=CICIWn
Hn=xEXP(EIA13A13+FIA13)
Hn=GIHn
A15=WR-B
A14=xEXP(A15A15F/Wn)
Yn=xDIVIDE(250A14A,3HnWn)
JUMP6,S=2
A7=A7+Yn
JUMP7
6)A8=Yn
7)REPEAT
A4=4A7+2A8+A2
A4=A3A4
8)A5=A4
A13=2A3
A3=A3/2
A8=A7+A8
A7=0
A6=1
11)B=3A3A6V
A13=xLOG(B)
Wn=xEXP(2DIA13)
Wn=CICIWn
Hn=xEXP(EIA13A13+FIA13)
Hn=GIHn
A15=WR-B
A14=xEXP(A15A15F/Wn)
Yn=xDIVIDE(250A14A,3HnWn)
A11=xMOD(3A3A6-Z)
A7=A7+Yn
A6=xINTPT(A6+2.5)
JUMP11,A11>A12
A4=4A7+2A8+A2
A4=A3A4
A10=xMOD(A4-A5)
JUMP8,A10>0.005
Y=A4
10)L=1(1)N
X=ZL/Vn
X=xEXP(FXX)
Zn=XY
J=R-1
An=5J
An=An+L
x7(300+An)Zn,1
REPEAT
REPEAT
L=N
P=M
O=5
M=4
N=1
Bn=301
T=13
I=4
J=0
An=89
Q=6
R=0
Cn=201
DOWN1/1
UP
PSA
xLOG
xEXP
CLOSE
```

CHAPTER3
VARIABLES 2
1)C1=2.969031
C2=2.016008
C3=1.431422
C4=0.992267
C5=0.793651
C6=0.628411
C7=0.544444
C8=0.483472
C9=0.386577
C10=0.304200
D1=0.832328
D2=0.849915
D3=0.870930
D4=0.894351
D5=0.899670
D6=0.907270
D7=0.904057
D8=0.892725
D9=0.896488
D10=0.903438
E1=0.163218
E2=0.076580
E3=0.064920
E4=0.045949
E5=0.020738
E6=0.020347
E7=0.000700
E8=-0.023357
E9=-0.034751
E10=-0.038906
F1=-0.325643
F2=0.497889
F3=0.444747
F4=0.483177
F5=0.664714
F6=0.576763
F7=0.748539
F8=1.030711
F9=1.151964
F10=1.173229
G1=4.485213
G2=0.541334
G3=0.764965
G4=0.795191
G5=0.497800
G6=0.643114
G7=0.365135
G8=0.129320
G9=0.074202
G10=0.059499
UP
CLOSE

```
CHAPTER0
VARIABLES2
610(I)
JUMP1,I≠1
DOWN100/1
1)HALT
2)600(I)
JUMP2,I≠27
3)600(I)
JUMP3,8>I
JUMP3,I>18
READ(V)
READ(A)
READ(D)
READ(E)
READ(C)
READ(U)
READ(M)
J=1(1)M
READ(WJ)
REPEAT
READ(N)
J=1(1)N
READ(ZJ)
REPEAT
J=1(1)N
x7(88+J)ZJ,1
REPEAT
Dn=N
Fn=M
DOWN1/3
J=1(1)4
T=14
DOWN121/1
REPEAT
T=1
DOWN121/1
T=14
DOWN121/1
x7(1)A,1
x7(2)V,1
x7(3)C,1
x7(4)D,1
x7(5)E,1
L=1
P=1
O=0
M=7
N=0
T=2
Bn=1
Q=0
R=3
S=38
DOWN2/1
M=3
N=3
T=I+7
Bn=2
Q=0
R=4
S=9
DOWN2/1
P=3
O=0
M=4
N=2
T=14
Bn=3
Q=0
R=5
S=37
DOWN2/1
J=1(1)4
T=14
DOWN121/1
REPEAT
I=I-7
X1=0
Y1=0
X2=D
F=xLOG(10)
F=-4F
G=xLOG(X2)
Wn=xEXP(2DIG)
Wn=CICIWn
Hn=xEXP(EIGG+FIG)
Hn=GIHn
Y2=xEXP(FEE/Wn)
Y2=xDIVIDE(5000Y2A,HnWn)
JUMP4,Y2>C
Z=-1
T=8
DOWN121/1
T=12
DOWN121/1
JUMP5
4)B=X2
JUMP6,Y2=C
7)B=xDIVIDE(X1+X2,2)
W=X2-X1
G=xLOG(B)
Wn=xEXP(2DIG)
Wn=CICIWn
Hn=xEXP(EIGG+FIG)
Hn=GIHn
En=D-B
En=EnEn+EE
H=xEXP(FEn/Wn)
H=xDIVIDE(5000AH,HnWn)
JUMP6,0.1>W
JUMP8,H>C
X1=B
JUMP7
8)X2=B
JUMP7
6)Z=B/V
x7(1)B,1
x7(2)Z,1
x7(3)U,1
L=1
P=3
O=0
M=5
N=1
T=8
Bn=1
Q=0
R=9
S=45
DOWN2/1
5)T=14
DOWN121/1
DOWN1/2
830,0
JUMP2
PSA
xLOG
xEXP
CLOSE
```

```
*********

DOSAGES RECEIVED AT VARIOUS POINTS AFTER TRIGGERING OF ALARM
INPUT DATA
INSTANTANEOUS POINT SOURCE OF STRENGTH
WINDSPEED
ALARMS CRITICAL CONCENTRATION IS ....
ALARMS POSITION DOWNWIND OF SOURCE ..
ALARMS POSITION CROSSWIND OF SOURCE .
OUTPUT DATA
ALARM IS TRIGGERED WHEN CLOUD HAS TRAVELLED .
TIME TAKEN BY ALARM TO SIGNAL THE ATTACK IS .
TIME TROOPS ARE UNPROTECTED WHILST MASKING IS
ALARM IS NOT TRIGGERED
D-W DISTANCE                                                        *
FROM  SOURCE                                                        *
   METRES        C-W DISTANCE  METRES

MET. CAT. .....H
MET. CAT. .....I
MET. CAT. .....J
MET. CAT. .....K
MET. CAT. .....L
MET. CAT. .....M
MET. CAT. .....N
MET. CAT. .....O
MET. CAT. .....P
MET. CAT. .....Q
>

*******>
******)xo
```

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